WEATHER AND CIRCULATION TYPES ACCOMPANYING THERMAL AND HUMIDITY CONDITIONS UNFAVOURABLE TO THE HUMAN HEALTH IN SUMMER IN KRAKOW (POLAND)

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ABSTRACT. – Weather and circulation types accompanying thermal and humidity conditions unfavourable to the human health in summer in Krakow (Poland). The paper presents the results of a study analysing the frequency of occurrence and patterns of change in the human perception of temperature in relation to types of weather and circulation in Krakow. The Humidex index used for the purpose was determined at three measurement times (6, 12, 18 UTC) with data spanning the period 1961-2012. The frequency of occurrence of all types of discomfort situation was found to be on the increase. Days with some discomfort occurred most frequently during non-advection situations, (especially in the centre of a meteorological high or anticyclonic wedge), accompanied by transformed polar maritime air or continental polar air. The weather varied greatly on such days, from cloudy to sunny and with or without precipitation. Days with high discomfort levels were associated with the advection of tropical air accompanied typically by very hot, sweltering weather, and by dry, very sunny weather.

Keywords: Humidex index, unfavourable bioclimatic conditions, weather types, circulation types.

1. INTRODUCTION

The growing global warming effect has a strong impact on the life and health of large numbers of city dwellers. Much of that population is meteoropathic, i.e. sensitive to the weather and its dynamic change.

Depending on the intensity, air temperature and humidity can either have an effect of increasing resistance or a debilitating effect. Daily air temperature fluctuations within the range 18-23°C do not affect human body temperature, but higher temperatures or temperature changes, even short-term, may cause irregularities in the thermal management of the human body (Kozłowska-Szczęsna et al. 2004).

High air temperatures reduce physical and mental efficiency, blood pressure, increase the heart rate, quicken breath, increase sweating and cause a deterioration of well-being. In extreme cases this can lead to death in senior citizens or people suffering from cardiovascular diseases (Kozłowska-Szczęsna et al. 2004, Tuller 1997).

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The city of Krakow is located in the inversion-prone Vistula river valley with an adverse bioclimate characterised by temperature inversions, poor air ventilation and frequent *foehn* situations (Matuszko, Piotrowicz 2007).

The condition of the city's air also contributes to these situations (Bokwa 2007). The urban and industrial expansion after the Second World War caused an increase in air pollution and affected the perception of temperature. According to Błażejczyk's classification system, which is based on research on Poland's biothermal variation, Krakow is located in a region with the highest average annual temperature measured at 12 UTC (10.5-11.4°C) (Błażejczyk 2004). Kozłowska-Szczęsna (1997) classified Krakow as a low-stimulus area meaning that the human body does not have to adapt itself on arrival in, or to readapt itself on departure from, Krakow. Krakow lies in an area with above-average positive conditions on Błażejczyk's bioclimatic map (Błażejczyk 1992).

The bioclimatic research in Krakow included the impact of weather conditions on death rates in the city (Wiecha 1952). The author demonstrated that warm and cold fronts were the most meteorotropic, while occluded fronts were the least meteorotropic.

Hess et al. (1989) also investigated the bioclimate of Krakow by looking at various biometeorological indicators. They found that the urban heat island reduced thermal stimuli between autumn and spring, but it had the reverse effect in summer. Niedźwiedź et al. (1994-1995) claim that atmospheric circulation was the fundamental driver of the bioclimatic variability in Krakow.

Błażejczyk et al. (2003) focused on the variability of biothermal conditions in Krakow during the 20th c., and specifically on the fluctuation of atmospheric circulation, air temperature, wind speed and cloud cover. The authors found that perceptible temperature (STI) rose by 2.24°C during 100 years. They also observed an intensification of thermal strain around midday, which during the summer is driven by, among other factors southern component of meridional circulation (Błażejczyk et al. 2003).

This study reports on the frequency of occurrence and patterns of change of each Humidex category in Krakow during the period 1961-2012. A special focus is on days with index values above 39°C when humans experience a great deal of discomfort and there is a high risk of heatstroke in the open air or after a short effort. Weather and circulation types on such days were also analysed for practical reasons.

2. HUMIDEX INDEX

One method used to assess the threat posed by weather in the summer season to human health is the Humidex index (HD). It is expressed in degrees Celsius [°C] and calculated taking into account air temperature (t) and vapour pressure (e) (or another humidity indicator, such as relative humidity) (Santee, Wallance 2005) according to the formula: $HD=t+0.5555\cdot(e-10)$ (Kozłowska-Szczęsna et al. 2004). Humidex is therefore a measure of the perceptible

temperature and expresses the combined effect of temperature and humidity on the subjective human sensation of heat.

The Canadian weather service has developed a scale to measure the danger from temperature and humidity corresponding to Humidex values greater than 23.0°C (Table 1). The scale is mainly used in Canada and the USA, but is also used in southern European countries (Błażejczyk 2004). Mastrangel et al. (2007) used Humidex in a study of the impact of the intensity and persistence of heat waves in Venice on the rate of sickness and hospitalisation. Charalampopoulos et al. (2012) employed the index to investigate thermal comfort in the Athens urban area looking at areas with different types of development and proportions of green areas and areas in the city's periphery. Dobek et al. (2008) used the Canadian scale to perform their study in Poland.

3. DATA AND METHODS

As has been stated before, this study looks at the frequency of occurrence and patterns of change of each Humidex category (Table 1) in Krakow measuring the three terms (6, 12, 18 UTC) during the period 1961-2012. The meteorological data come from a climatological station located in the city centre which gives a very good reflection of conditions predominant in urban areas in Central Europe.

The data on circulation types, air masses and atmospheric fronts were sourced from the *Calendar of circulation types for the territory of southern Poland* developed by T. Niedźwiedź (2012). As Krakow is located centrally in the area covered by the Calendar, the data can reasonably be regarded as highly reliable. The Calendar involves 21 types of synoptic situation, including 10 cyclonic, 10 anticyclonic and one undetermined type (x). The capital letters N, NE, etc. mark the advection direction, while the letters "a" and "c" denote the types of pressure system.

Linear regression was used to analyse patterns of change in human perception of thermal conditions.

In total 71.3% of all days during the study period had neutral conditions at midday (12 UTC), i.e. a Humidex of less than 23.0°C, and there were no cases of extreme danger (HD≥54.0°C) (Table 1). The potential period during which any discomfort level could arise lasts from March to November. The earliest cases (HD>23.0°C) were recorded on 20 and 21 March 1974 and on 26 March 1981, and the latest on 2 November 1968. August had the greatest frequency of days with "some discomfort" (HD>23.0°C) while July featured the greatest number of days with "considerable discomfort" (HD>29.0°C) (Table 1). Days with great discomfort (>39.0°C when heatstroke can occur after even short physical exercise) were relatively rare at 22 in 16 years and were concentrated in the period between June and August, peaking in the latter month.

Table 1. ***Scale of danger and frequency [%] of thermal sensations in man determined on the basis of the Humidex index in Krakow in the period 1961-2012***

Thermal sensations	Humidex	III	IV	V	VI	VII	VIII	IX	X	XI	III-XI
1. Caution	23.0-28.9	0.2	4.5	21.7	32.3	33.5	35.9	23.8	8.3	0.06	17.9
2. Extreme caution	29.0-38.9	-	0.3	6.8	19.6	30.7	30.1	7.9	0.3	-	10.7
3. Danger	39.0-53.9	-	-	-	0.06	0.6	0.7	-	-	-	0.15
4. Extreme danger	≥54.0	-	-	-	-	-	-	-	-	-	-
1. Some discomfort. Fatigue possible with prolonged physical activity											
2. Considerable discomfort. Heatstroke possible with prolonged physical activity											
3. Great discomfort. Heatstroke possible even with brief exertion											
4. Heatstroke imminent in open terrain											

It is evident that the highest values of Humidex in Krakow are recorded at midday (Fig. 1). During the study period, there were 1624 days (11% of total days) with varied levels of discomfort occurring only at 12 UTC. There were sporadic days, when "some discomfort" was felt only in the morning (31 days) or in the evening (32 days).

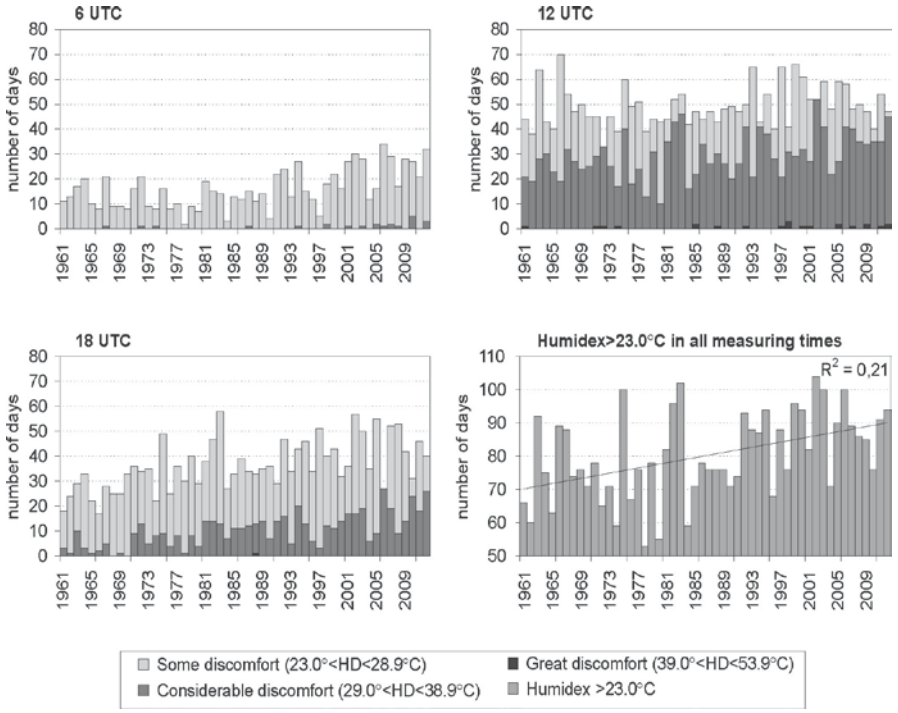

Fig. 1. ***Number of days with three different degrees of risk in each of measuring times (6, 12, 18 UTC) and number of days with HD>23.0°C in all measuring times in Krakow in the period 1961-2012***

There were also days with discomfort at all three measurement times, including the record year of 2012 (34 days) and record month of July 2006 (19 days) (Fig. 1). A clear trend to an increase in the number of such days has been identified starting in the 1960s (16.8 days per 50 years, $p<0.05$).

During the last 52 years, there has been an increase in the number of cases for all levels of discomfort and at all measurement times; 15.7 at 6 UTC, 19.3 at 12 UTC and 34.1 days per 50 years at 18 UTC (in all cases $p<0,01$). This growth was the most prominent in the evening ($p<0.01$), including for "some discomfort" by 18.1 days per 50 years and for "considerable discomfort" by 15.3 per 50 years. At the morning measurement time, the trends were less strong and included 14.3 days per 50 years for "some discomfort" and 1.4 days per 50 years for "considerable discomfort". The change at midday was the weakest, including a statistically insignificant, but positive, trend for "some discomfort" (5.6d/50y), stronger trend for "considerable discomfort" at 12.9 days per 50 years and for "great discomfort" 0.8 days per 50 years ($p<0.01$).

Looking at extreme cases there were no individual years with more than three days with "great discomfort" and on only one day did Humidex exceed 39°C at two measurement times (24 July 1988). On that day, its value was 42.1°C at 12 UTC and 40.2°C at 18 UTC and the day belonged to a longer spell with "discomfort" (22-27 July 1988).

Looking at synoptic situations the highest proportion of days with caution (HD>23°C) was during non-advection situations: anticyclonic centre (Ca) or wedge (Ka) (21% combined) and cyclone centre (Cc) and trough (Bc) (18% combined). Taken together, all anticyclonic situations, regardless of their advection sector, dominated slightly at 55% of all situations (Fig. 2). The most frequent air masses on such days included polar maritime old (transformed) – 31% and polar continental (30%). There were no fronts on 61% of days, and on 19% there was a cold front. The maximum temperature was typically greater than 25°C and relative humidity exceeded 50%. Cloud cover varied widely from cloudless to full cloud cover. In terms of precipitation, 55% of these days were dry, but 7.9% featured more than 10 mm total precipitation, often thunderstorm precipitation.

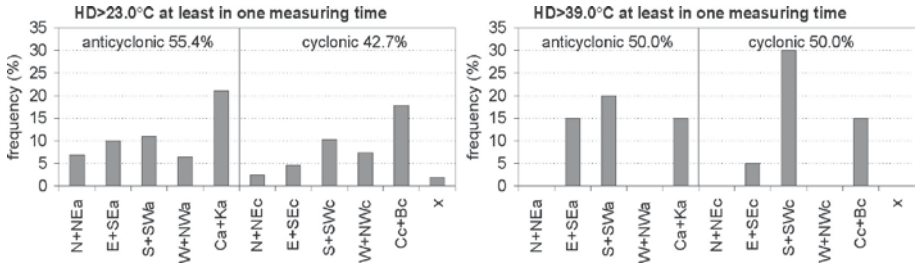

Fig. 2. Frequency of occurrence (%) of days with Hunidex above 23.0°C and 39.0°C at least in one measuring time for particular circulation types in the period 1961-2012

Days with HD>39°C were equally split between cyclonic and anticyclonic situations (50% each). Also equally split were non-advection situations at 15% (Ca+Ka and Cc+Bc) (Fig. 2). Tropical advection clearly dominated at 70% and the remaining 15% was accounted for by polar continental air. By and large these were front-free days (70%) and, rather unsurprisingly, very hot (tmax>30°C) and sweltering (e≥18.8 hPa). With sunshine duration exceeding eight hours, 27% of the days with precipitation.

4. CONCLUSIONS

The study employing the Humidex index, known to help determine the degree of danger from air temperature and humidity (Dobek et al. 2008), arrived at the following conclusions pertaining to the period 1961-2012 in Krakow:

– The most frequent time of day with any type of discomfort (HD>23.0°C) was midday (12 UTC);
– No cases of extreme danger (HD≥54.0°C), including the risk of heatstroke in open terrain, were found;
– The highest number of days with "some discomfort" were recorded in August, with "considerable discomfort" in July; the discomfort season was identified to span the period from March to November;
– The greatest increase in discomfort situations was found in the evening (18 UTC), including "some discomfort" increasing by 18.1 days per 50 years and "considerable discomfort" by 15.3 days per 50 years ($p<0.01$); there was also some increase in discomfort situations at the other two times of day;
– Days with any discomfort (HD>23°C) most frequently occurred during non-advection situations (anticyclonic or cyclonic centre (Ca, Cc), anticyclonic wedge (Ka) and through of low pressure (Bc)), polar maritime transformed (31%) or polar continental (30%) air masses, the absence of fronts (61%), air temperatures higher than 25°C and humidity higher than 50%. There was a mix of cloudy and sunny, dry and wet days;
– Days with HD>39°C were accompanied equally by cyclonic and anticyclonic situations (50% each); mostly occurring during days with tropical advection (70% days), but also with polar continental air (15%). There was typically an absence of fronts (70%). These hot (tmax>30°C) and sweltering (e≥18.8 hPa) days were sunny (more than eight hours of sunshine) and typically also without precipitation.

Acknowledgement:

The authors are grateful to the Polish-Hungarian bi-lateral project, TÉT_10-1-2011-0037 for the partial support.

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